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A PROPOSED METHOD FOR THE TRANSIT LINING OF HIGH-SPEED TRACK

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A PROPOSED METHOD FOR THE TRANSIT LINING OF HIGH-SPEED TRACK

Neil R. Berndt

ABSTRACT

Sometime ago, a directive was issued by the Chief Engineer of the New York Central System, Lines West, recommending the use of transit-lining in preference to other methods of alignment. Many of the present methods of transit-lining high-speed track are unsatisfactory because of the lack of a simplified, standard procedure.

The purpose of this report is to present a proposed method of transit-lining high-speed track, which has been developed by an investigation of surveying geometry and made possible by modern computational devices.

This investigation reveals a process whereby tangent track may be established from a graph of the existing conditions, curve data may be computed in the office, and the throw of the track may be limited, but yet selected with a definite corrective relationship to a proposed center line.

This proposed method has been used by the Division Engineer's Office at Jackson, Michigan, since the summer of 1951. During this period it has added simplicity to the work, saved time, reduced lining and engineering costs, and produced a good quality of work. It is therefore recommended that a study be made to determine the possibilities for the use of this method as a standard procedure.

Introduction

The over-all methods of transit lining high-speed track need clarification for the convenience of the instrumentman. At times the instrumentman is left to his own initiative and better judgment to establish a method of transit lining curves. Before any criticism is made of the instrumentman, it should be recognized that he lacks a simplified, standard procedure of establishing alignment.

It is the author's opinion that a standard procedure should be available for the instrumentman so that he isn't required to be a curve and tangent specialist to expedite good alignment. This method should not only embrace good alignment but should also reduce track lining and engineering costs.

This report presents a proposed standardization for the transit lining of high-speed track. The first part includes the lining of tangent track by graphing the existing conditions with respect to a random line. A procedure is introduced in the second and third parts whereby simple and compound curves can be analyzed in the office from a preliminary curve traverse. A method is proposed by which throws can be limited, but still selected with a definite corrective relationship to the proposed center-line of track. The advantages and disadvantages are listed and discussed at the end of the report with a final recommendation that this proposed method be adopted as a standard procedure.

The theory of the development is quite fundamental and has been limited to avoid extraneous material. This report has made no attempt to evaluate the reduced costs brought about by the saving of time and the establishment of better alignment over other methods. Because of the variance in transit-lining methods, it is almost impossible to evaluate these reduced costs.

Part I: Lining Tangent Track

The main difficulty in the lining of tangent track is the determination of the straight line which will cause the least amount of throw and still maintain standard track centers. The first inspiration is to run line between two points chosen from rather uniform straight track with standard track centers. In many instances if the line so chosen is long, excessive throws and substandard track centers are encountered; or if the line is projected into a curve, a distorted point of intersection is formed.

Random Tangent Line

A more desirable method of selecting a tangent line is to obtain a true physical picture of the tracks as they lie on the roadbed, which can be accomplished by shooting long random lines from curve to curve, knoll to knoll, crossing to crossing or any combination of the above. The line is established by projection between random control points on center line of track and transverse offset measurements taken at 100 foot intervals from said random line to gauge of one rail of track to be lined. It is sometimes desirable for ease and accuracy of field work to project random line control points to locations on track shoulder, as per example, "Tangent Graph No. 1, Part A". Track center measurements and clearances to any limiting facilities, such as bridge piers and signals, are also required to complete the necessary information. The graphing of the offsets and track centers then presents true conditions. By adjusting the random line on the graph, track throws can be minimized, kinks hidden, and track-centers planned. Also on curves, the point of intersection, determined by the projection of the tangent lines, will more likely coincide with the original.

It becomes apparent that extreme care and accuracy in the random tangent line establishment is essential. Experience has proved that the best lines can be established in the early morning or early evening hours to avoid heat wave distortion during the summer months. Under these conditions, successful results have been attained with lines as long as two miles. Effort toward the longest line possible should always be made and work suspended when adverse conditions, in the nature of heat waves and wind, are encountered.

Field Party and Work

A field party of four, consisting of a transitman, rodman, and two tackmen, seems to work out satisfactorily. After choosing the extremities or control points of the random line, the transitman sights on the distant rodman and signals for an intermediate target to be set on line by the tackman at a point approximately 2000 feet ahead of him. This target then becomes the foresight for this segment of line, and tacks are set in track ties at 100 foot stations for the 2000 foot interval. The transit is then moved to the target point and the process is repeated until completion to the initial distant

point.

Tangent Example

Tangent Graph No. 1 is an actual example of a half-mile random line between two curves on the M.C.R.R. Main Line at Mile Post D-156, Mattawan. Although this graph could be a better example of deleting and balancing throw, it does demonstrate the flexibility for minimizing throw through the crossover and street crossing, the provision of standard track clearances to the overhead road bridge, and the determination of centers to the eastward main track.

To compose the graph, field distances (random line to rail of track to be lined and track centers before lining) are plotted and the points of limited throw specifically noted. If random line A-B was accepted, which is often the case, the proposed throw would be the combined red and green shaded areas. By adjusting line A-B to the new position C-D, the throw areas become those shaded red and blue, thus deleting the area in green.

In choosing line C-D, consideration is given to the following: (1) balancing the throw for economical lining procedure, (2) points of limited throw involving track clearances, track-centers, and crossings, and (3) providing future control for lining adjacent tracks.

The third point above is illustrated on Part D of the graph. The proposed throws, with respect to the adjusted line C-D, are superimposed on the plotted track centers, and a new line E-F is developed. Line E-F is determined in the same manner as line C-D with the same degree of flexibility, which results in an independent line with a definite relationship to line C-D.

When a satisfactory determination of lines C-D and E-F has been made on the graph, the lateral displacements from the initial random line can then be read or scaled directly for use in adjusting the line in the field. The ease of this operation is illustrated on Part C of the graph. The new tangent is then ready for staking.

Staking The New Tangent Line

The computed displacements are laterally offset from the random line tacks in the ties, and the new line stakes are driven between the ties to form the new tangent line. One practical way to accomplish this detail is to measure the distance between the base of the rail and the random line tack in the tie. To this distance, add or subtract the computed lateral displacement to give the distance from the base of the rail to the new tangent line. By using the base of the rail as a parallel straight edge and transferring the latter distance, the stake is then set in the adjacent tie crib to form the new tangent line.

Part II: Transit Lining Simple Curves

The transit lining of a simple curve by a complete operation in the field can be a lengthy process, but by this proposed method the curve can be analyzed in the office from a preliminary curve traverse to save man hours and to yield a better quality of work. After the new curve is established in the field, a method is proposed by which throws can be limited, but still selected with a definite corrective relationship to the proposed center-line of track.

The proposed curve standardization is based upon a three day work period

for an average simple curve. The first day is spent gathering the initial field information, the second day computing the curve in the office, and the third day staking the curve. However, after the curve is once monumented by the proposed standardization, line may be reestablished in one day.

Initial Field Work

To form the basis of this curve analyzation, the existing curve is located with respect to a traverse which is established between the accepted curve tangents.

Curve Tangents

Curve alignment is primarily dependent upon the acceptance of predetermined tangent lines. The determination of tangent lines has been discussed in Part I of this treatise. Unless suitable tangents are established in advance, excessive throws are often encountered within the curves. Misplaced easements, faulty superelevation, and "dog legs" often make it haphazard and unwise to split gauge at any two arbitrary points to establish tangent lines. Therefore, when transit-lining curves, a random tangent line of at least 2000 feet, if available, should be run at each end of the curve.

Curve Traverse and Track Location

As the actual point of intersection on high speed curves is usually inaccessible, it therefore becomes necessary to run a curve traverse to enable computation of this point and subsequent curve data.

Figure No. 1 is an example of a traverse of a simple curve on the M.C.R. R. at Mile Post D-123.38, Battle Creek, Michigan. The procedure for the illustrated field data is obtained in the following sequence:

(1) Primary hubs of the traverse are conveniently located on the outside shoulders of the roadbed and at distances which will permit line and chainage to fall within the roadbed limits. In the example it was possible to use corrected random line tangent points A and B, as they fulfill this requirement.

(2) With the transit on line between primary hubs, secondary hubs are set on line at intervals of approximately 300 feet throughout the length of curve.

(3) During step (2) all internal angles at the primary hubs are measured by repetition, and all distances between primary and secondary hubs are accurately measured.

(4) Tracks are located with reference to the traverse by radial offsets from the center-line of tracks to the hubs as designated by r_{A_0}, r_A, r_{A_1}, and so on. This measurement is accomplished by swinging the tape from the hub, reading the smallest measurement to the rail, and adding one-half of the gauge.

The above completes the initial field work and provides the control for staking the calculated curve. Desired results from computations are entirely dependent upon the accuracy of this initial field work, hence the stress upon chainage and measurement of angles.

Office Work

All curve data is developed in the office from the initial field work. Whereas the usual curve development is based upon trigonometric principles, this trial and error method embraces the use of a coordinate system by analytic geometry which has proved to have many advantages. Among those

most readily apparent is the complete analysis of the characteristics of the curve, controlled alignment, and the simplicity for standardization of method and preservation of data.

Figure No. 2 illustrates the development of the field traverse data shown in Figure No. 1 and is processed in the following sequence:

(1) Using Form No. 1, compute the latitudes and departures of the curve traverse. Then figure the hub coordinates from the latitudes and departures with the origin being taken as the point of intersection.

(2) In Trial No. 1, using Parts A and B of Form No. 2, choose a curve radius and its corresponding spiral data and compute the coordinates H and K for the center of the curve.

The initial choice of the radius is made from previous records or knowledge of the curve. The y coordinate K of the center of a simple spiraled curve is equal to R + o, while the x coordinate H is equal to $(R + o) \tan \frac{I}{2}$ or $K \tan \frac{I}{2}$.

(3) Using Form No. 3, Part A, Trial No. 1, substitute the values of H, K, and R derived from step (2) and compute the throw for hub A_1, which is used because of its location to the center of the curve.

The radius plus the radial offset, $R + r_{A_1}$, is equal to $[(H - A_{1_x})^2 + (K - A_{1_y})^2]^{\frac{1}{2}}$. Subtract the radius R from $R + r_{A_1}$ to determine the computed radial offset r_{A_1}. The difference between the calculated and the field measured radial offset is the computed throw.

(4) In all probability the radius of curvature in Trial No. 1 will result in a large calculated throw; therefore, another attempt at matching the field condition is required. Using Part C in Form No. 2, substitute the value of the throw at hub A_1 for the plus or minus throw under Trial No. 1.

The approximate radius correction is equal to the throw at A_1 divided by the exsecant of $\frac{I}{2}$. This radius correction applied to the radius of trial No. 1 provides an estimated radius for Trial No. 2 which gives the curve that should pass through hub A_1 with little or no throw.

(5) Substituting the corrected radius into Trial No. 2, repeat the process under steps (2) and (3) above. In addition, compute the throws at all hub points.

(6) Applying the data from Trial No. 2 to Graph No. 2, the throws and resulting track centers are analyzed to determine the characteristics of the curve.

On Graph No. 2, approximate horizontal scale distances are used for the location of the hubs and points of curve with relation to the center of curve. Trial No. 2 throws are then plotted at the hub points.

The graph shows clearly whether the curve should be solved as a simple curve or as a compound curve in order to conserve throw. In the example, a simple curve solution was used. Compound curves will be explained in Part III of this treatise.

The graph shows another function by determining the relative variation in throw throughout the curve for a given throw at the center of the curve. For instance, a change of 0.30 foot throw at the center of the curve would cause a $(0.30)\ [1 - (\frac{370}{1000})^2] = (0.30)\ (0.86) = 0.26$ foot change at hub point B. Thus, the effects upon the curve of any change of throw in Trial No. 3 may be pre-

dicted without the actual computation of that trial. After selecting a change fo throw at the center of the curve which will result in the least amount of throw throughout the curve, the radius is again corrected and subjected to Trial No. 3. A check of the work is provided when the new computed throws are in agreement with the expected throw obtained from Graph No. 2.

(7) After accepting the results obtained in Trial No. 3 as the best to fit the field conditions of the curve, the radius hub angles and stations are computed using Parts B and C of Form No. 3.

The angle i is the angle subtended at the center of the curve as indicated by i_{A_1} in Figure No. 2. The sine of angle i is equal to H - A_{1_x} divided by $R \pm r_{A_1}$. The compliment of angle i, 90^0 - i, plus the xx bearing angle of the respective hub point, is equal to the radius hub angle.

The arc distance, L_i, from the P.C. to any center-line hub point is defined as a point for the new center-line of track which is established from a traverse hub point by using the computed radius hub angle and radial offset. If the east P.S.C. is to be considered as Station 0+00, an adjustment should be made by subtracting one-half of the spiral length from L_i. In compound curves it will become apparent that another adjustment will have to be made when continuing stationing from one degree of curvature to another.

Remaining Field Work

After accepting the computated data derived from Trial No. 3 and placing the results in a field book, the curve is ready for staking.

Staking The Curve

The curve may be staked by two different methods depending on the condition of its present line and on the maximum allowable throw. The ideal way is to stake the actual proposed center-line, but often this is impossible because of excessive throws, a shortage of manpower, and the necessity to keep the track on a previously prepared tamp.

The next best method is to stake an alternate center-line which minimizes throw, meets points of limited throw, and still retains a relationship to the actual proposed center-line. This is easily accomplished by graphing the actual proposed throws and developing alternate throws as shown in Graph No. 3.

After a few years of corrective lining by the proposed method shown in Graph No. 3, most curves can be eventually lined to their actual proposed center-lines. Therefore, this graphing procedure is always working towards a standard curve. However, it is the author's contention that if a curve possesses good riding qualities, it never has to be completely lined to its theoretical center-line.

In either method the center-line hubs are established by turning off the computed radius angles from the traverse hub points and laying off the distances equal to the radial offsets obtained in Trial No. 3. By using the established center-line hubs as actual curve transit stations, the curve may be deflected in. A check of the work is provided when the total deflected angle at any center-line hub, turned between its two adjacent hubs, is in agreement with its theoretical deflection.

Monumenting The Control Points

To avoid duplication of the above preliminary work in future years, all

control points should be monumented with iron pins. These iron pins may be placed on the center-line of the track every 1000 to 2000 feet on tangents and 300 to 400 feet on curves to help facilitate the reestablishment of future line. Some instrumentmen may prefer to place iron pins at the traverse hub points in preference to setting iron pins on the center-line of curves. This preference might have the advantage that the pins are less apt to be disturbed if properly placed, but it has the disadvantage of having to establish center-line hubs during each transit-lining of the curve. Coupled with the monumenting of the control points is the placement of concrete markers on the roadbed shoulder designating the location of spirals and points of compound curvature, the degree of curvature, the number of the curve, and the amount of superelevation.

Part III: Transit Lining Compound Curves

Compound curves are more independent and difficult to transit-line than simple curves, but by this proposed method it is possible to expose the characteristics of the curve and locate the points of change in degree of curvature. By substituting three accepted field conditions in their corresponding analytic geometry formulas and solving simultaneously, the coordinates of the center of the respective curve and the radius of that particular trial can be computed. These values are then placed in Form No. 3 and handled in the same manner as a simple curve.

In order to present a typical compound curve and some of the possible compound curve problems, the curve at Mile Post D-125.20, Battle Creek, has been used and is illustrated in Figure No. 3 and Graph No. 4. After understanding this example and its combination of analytic geometry formulas, one should be able to solve any compound curve using the same principles.

In treating this example as a simple curve, it is shown by "Trial No. 2, Simple Curve" in Graph No. 4 that excessive throws would be encountered. Therefore, to minimize throws, it is necessary to compound the curve which is processed in the following sequence.

Trial No. 1, West End

This particular trial is developed from the west end of the curve as indicated by Curve No. 1 in Figure No. 3. It is necessary to set up three simultaneous equations to solve for the three unknowns H_1, K_1, and R_1. The first equation insures that the curve will be tangent at an o_1 offset to the west tangent line. The second and third equations allow the curve to pass through two points in the existing curve, namely center-line hub points B and A_1. Points B and A_1 are chosen because of their relative location to the west end of the curve. It is a good practice to keep the distances approximately equal between the three equation points so that the curve may be more representative of the existing conditions.

The distance from the west tangent line to the center of the curve (H_1,K_1) can be found in the following manner. The normal equation of the west tangent line is

$$0.290106311\ H_1 + K_1 = 0.$$

Reducing the equation to the normal form, we have

$$\frac{{}^{a}H_1 + {}^{b}K_1 + c}{(a^2 + b^2)^{\frac{1}{2}}} = R_1 + o_1.$$

Substituting the values of a, b, and c from the equation of the west tangent line and assuming an approximate value of o_1 as 0.335, we have

$$\frac{0.290106311\ H_1 + K_1}{(0.290106311^2 + 1^2)^{\frac{1}{2}}} = R_1 + 0.335. \qquad (1)$$

The curve may be passed through the center-line hub point B by setting the sum of the squares of the sides equal to the square of the hypotenuse of the right triangle shown in Figure No. 3. Then

$$(H_1 - B_x)^2 + (K_1 - B_y)^2 = (R_1 + r_B)^2.$$

By substituting the coordinates of hub B and its radial offset, we have

$$(H_1 - 438.905)^2 + (K_1 - 127.329)^2 = (R_1 + 22.85)^2. \quad (2)$$

Likewise, the curve may be passed through the center-line hub point A_1. Then

$$(H_1 - 145.990)^2 + (K_1 - 39.583)^2 = (R_1 + 11.88)^2. \quad (3)$$

Solving equations (1), (2), and (3) simultaneously, we find H_1 = 1,133.681, K_1 = 7,657.479, and R_1 = 7,669.787. These values are placed in Part A of Form No. 3 and the throws determined at the center-line hub points A, A_1, A_2, B, B_1, and B_2 in the same manner as handled in Part II of this report. These throws are then plotted as shown by "Trial No. 1, West End" in Graph No. 4. Values of zero throw at the center-line hubs A_1 and B indicate a partial check of the computations.

Accepted Trial No. 2, West End

To reduce the throw at the center-line hub points B_1 and B_2, a negative 0.35 foot throw is introduced at center-line hub point B for the proposed "Trial No. 2, West End". This proposed adjustment will not appreciably change the three equations used in Trial No. 1.

The only possible change in equation (1) would be a new value of o_1. To obtain the new distance of o_1 for Trial No. 2, the o_1 distance from Trial No. 1 should be corrected using the radius computed in that trial. If the new o_1 distance is in close agreement to the one initially assumed, as it was in this case, it does not have to be corrected. Therefore, equation (1) of Trial No. 1 remains the same in Trial No. 2. The difference between the assumed and theoretical o distance will be explained later.

The only revision to equation (2) is the change in the value of the radial offset r_B to accommodate the proposed negative 0.35 foot throw at the center-line hub point B. The revised equation (2) is then

$$(H_1 - 438.905)^2 + (K_1 - 127.329)^2 = (R_1 + 23.20)^2. \quad (2)$$

Equation (3) remains the same because there is no proposed throw at center-line hub point A_1.

Again solving equations (1), (2), and (3) simultaneously, we find H_1 = 1, 158.170, K_1 = 7,774.707, and R_1 = 7,789.195. The new throws are then figured and plotted as shown by "Trial No. 2, West End" in Graph No. 4. This trial was accepted because the throws were not excessive and were reason-

ably balanced.

Trial No. 1, East End

This trial was developed from the east end of Curve No. 1 and continued to the east tangent line as shown by Curve No. 2 in Figure No. 3. The first equation of the necessary three equations determines the point of compound, the second passes the curve through the existing center-line hub A_0, and the third makes certain that the curve will be tangent at an o_2 offset from the east tangent line.

The two curves may be compounded by writing an equation involving their center coordinates and radii. It may be seen in Figure No. 3 that a right triangle exists which contains a relationship between these common properties. Then we have

$$(H_1 - H_2)^2 + (K_1 - K_2)^2 = (R_1 - R_2)^2.$$

By substituting the center coordinates and radius of Curve No. 1, we have

$$(1{,}158.169853 - H_2)^2 + (7{,}774.706960 - K_2)^2 = (7{,}789.195423 - R_2)^2. \quad (1)$$

(If the difference between the degrees of curvature of the two curves had been large enough to require an internal spiral, equation (1) would be revised to

$$(H_1 - H_2)^2 + (K_1 - K_2)^2 = [(R_1 - o) - R_2]^2.$$

The internal spiral o distance may be assumed for the initial trial and then corrected for subsequent trials by using the initial trial radius.)

By passing the curve through the center-line hub A_0, we have

$$(H_2 - 637.997)^2 + (K_2 - 0)^2 = (R_2 + 8.25)^2. \quad (2)$$

The distance from the east tangent line to the center of the curve (H_2,K_2) is

$$K_2 = R_2 + o_2.$$

Assuming an approximate value of o_2 as 0.349, we obtain

$$K_2 = R_2 + 0.349. \quad (3)$$

Solving equations (1), (2), and (3) simultaneously, we find $H_2 = 956.344$, $K_2 = 6{,}409.461$, and $R_2 = 6{,}409.112$. The throws are then figured and plotted as shown by "Trial No. 1, East End" in Graph No. 4.

Accepted Trial No. 2, East End

To obtain a better balance between the positive and negative throws, a positive 0.25 foot throw is introduced at center-line hub point A_0 for the proposed "Trial No. 2, East End". This proposed adjustment will not change equation (1) but will slightly alter equations (2) and (3) of Trial No. 1.

Changing the value of the radial offset r_{A_0} to accommodate the proposed positive 0.25 foot throw at the center-line hub point A_0, we have

$$(H_2 - 637.997)^2 + (K_2 - 0)^2 = (R_2 + 8.00)^2. \quad (2)$$

Using the corrected value of o_2 as 0.377, equation (3) is then

$$K_2 = R_2 + 0.377. \quad (3)$$

The simultaneous solution of the above three equations will give H_2 =

947.903, K_2 = 6,295.268, and R_2 = 6,294.891. In the same manner as before, the "Trial No. 2, East End" throws are developed and accepted as indicated on Graph No. 4.

Determination of the Point of Compound

The point of compound may be computed by the use of similar triangles. it can be seen in Figure No. 3 that

$$\frac{H_1 - H_2}{H_1 - P.C.C._x} = \frac{R_1 - R_2}{R_1}$$

Substituting the known values, we have

$$\frac{1{,}158.169853 - 947.903123}{1{,}158.169853 - P.C.C._x} = \frac{7{,}789.195423 - 6{,}294.891455}{7{,}789.195423}$$

Then $P.C.C._x = 62.135.$

In like manner $P.C.C._y = 62.999.$

Spiral Adjustments

To avoid making an extra trial to exactly recorrect the assumed o distance, the length of the spiral may be reasonably altered to fit the assumed o distance. For instance, a standard east spiral length for the above curve would be 240 feet, and its theoretical o distance would be 0.381 feet. But by changing the spiral length to 239 feet, the theoretical o distance changes to 0.378 feet as compared to 0.377 feet assumed in the computations. Since this discrepancy is so minute, the spiral distance is taken as 239 feet.

Radius Hub Angles and Stationing

The radius hub angles and stationing for compound curves are determined in the same manner as they are for simple curves. In this example the curve stationing is carried from the east P.S.C. to the west P.S.C. in the direction of valuation stationing. When computing the station at the P.C.C. of Curve No. 1 , it is apparent that a new stationing adjustment has to be figured to keep the stationing of Curve No. 1 in agreement with the stationing of Curve No. 2. The angle i at the P.C.C. is divided by the degree of curvature of Curve No. 1 to obtain L_{i_1}. The difference between L_{i_2} and L_{i_1}, plus one-half of the east spiral distance, is the new stationing adjustment for the stationing of Curve No. 1.

Advantages

1. The proposed tangent method offers absolute control in establishing tangent track and advocates the most economical lining procedure.

2. Curves are computed in the office, thus releasing field crews for other work which reduces the cost of transit-lining curves.

3. In most instances the quality and rate of the office computations are superior to those figured in the field.

4. A curve may be established from a traverse at intervals of approxi-

mately 300 feet, thus providing a center-line of track which is accurate and easily located.

5. By graphing the actual throws, an alternate center-line can be proposed which minimizes throw, meets points of limited throw, and still retains a relationship to the actual proposed center-line.

6. In conjunction with the previous advantage, the flexibility obtained by graphing allows larger initial throws to be proposed which tend to discourage an excessive number of degrees of curvature and hence encourages standardization.

Disadvantages

1. Since this method is comprehensive, it becomes involved at times.
2. It is necessary to have a calculator available for office computations.

Discussion and Recommendations

Under some other methods of transit-lining curves, the process is, in effect, closely related to "string lining". By these methods, the curve is arbitrarily divided into segments of different degrees of curvature without regard to standardization of the curve as a whole. The only satisfaction derived from these methods is the probable accomplishment of limited throw. In contrast, the method suggested in this report introduces a control which tends to discourage an excessive number of degrees of curvature and encourages standardization. From present knowledge the theory and practicality of this proposed standardization is superior to any other method known to the author.

In regard to the need of a calculator for office computations, it is found from experience that a ten column machine is needed to solve the simultaneous equations of the compound curve. During the development of this method, two demonstrative calculators were used: one was a Friden Model, STW-10, and the other was a Marchant Model, 10-EFA. Of the two calculators tested, it is felt that the Friden Model, STW-10, is more flexible and therefore the machine to acquire. This calculator may also be used for numerous other office computations, and it is becoming increasingly apparent that a machine of this type is necessary for the performance of routine work. (At the present time this office does not have any computational equipment).

During this investigation, difficulty was encountered in obtaining a suitable book of tables of the natural trigonometric functions. A book of tables was found, at a reasonable cost, which contains angles to the nearest second and natural functions to eight decimal places. The title of this book of tables is Natural Sines and Cosines to Eight Decimal Places, Special Publication No. 231, and is published by the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C.

It is acknowledged that this comprehensive method is intricate; however, it is felt that it is no more complicated than the average engineering design work. Probably the most complex part is the solution of compound curves by simultaneous equations. Familiarity with the method and the use of the proposed forms will greatly increase the speed of the office computations.

This report presents a proposed standardization for the transit-lining of

high-speed track. It includes the establishment of tangent track by graphing the existing conditions with respect to a random line. A procedure is introduced whereby simple and compound curves can be analyzed in the office from a preliminary curve traverse. A method is proposed by which throws can be limited, but still selected with a definite corrective relationship to the proposed center line of track.

In the event of any major main line track changes, such as a program of widening track centers, this proposed standard would adapt itself exceptionally well. Therefore, it is conceivable that the engineering and track lining costs could be greatly reduced through the use of this suggested method of transit-lining.

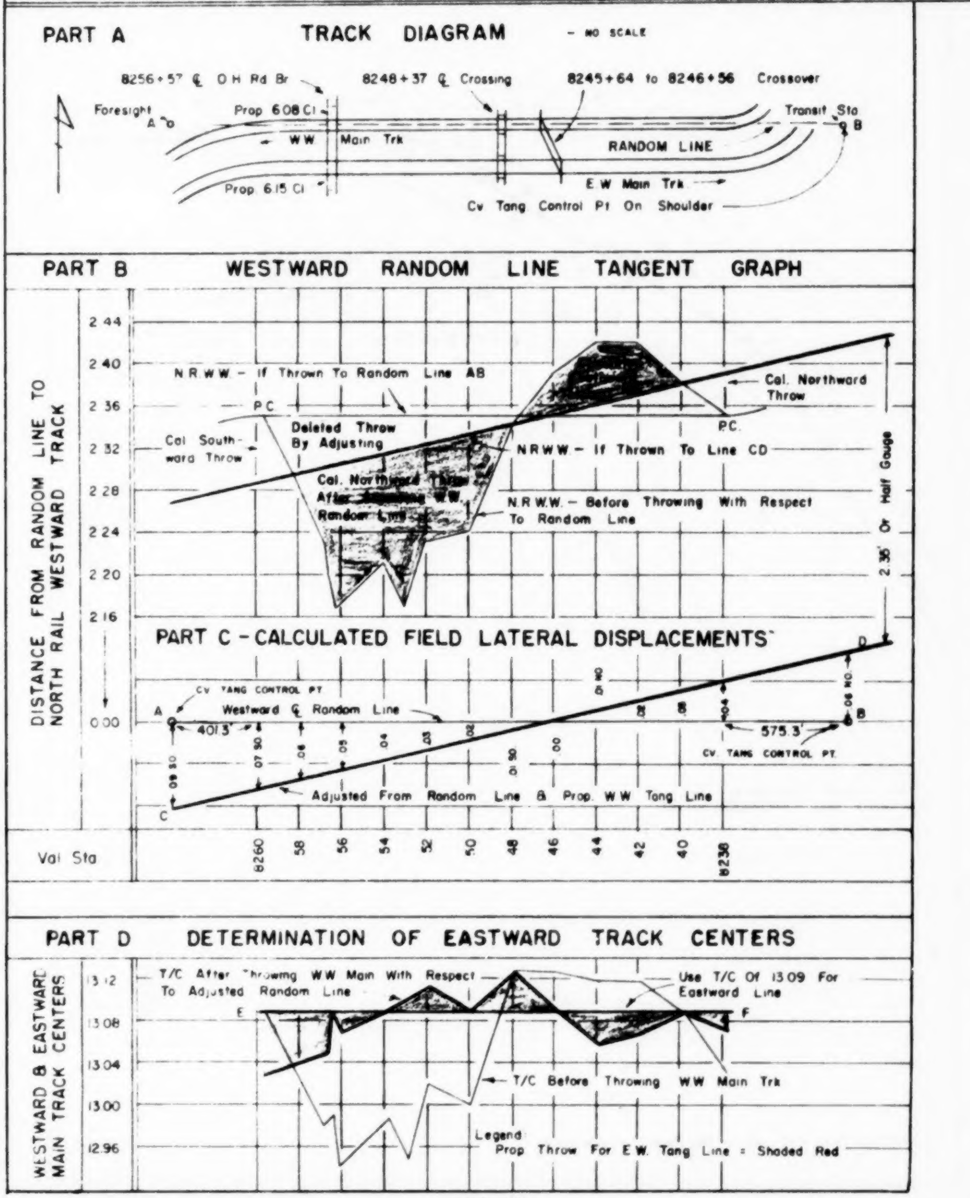
It is recommended that this method of transit-lining high-speed track be studied and possibly revised by competent engineers to determine the possibilities for its adoption as a standard procedure.

NEW YORK CENTRAL RAILROAD
ENGINEERING DEPARTMENT

COMPUTED BY N.R.B.

SUBJECT: TANGENT GRAPH NO. 1 — Westward Random Line Tangent Graph & Determination of Eastward Track Centers.

LOCATION: M.P. D-156 Mattawan DIVISION: Michigan DATE: July 11, 1950

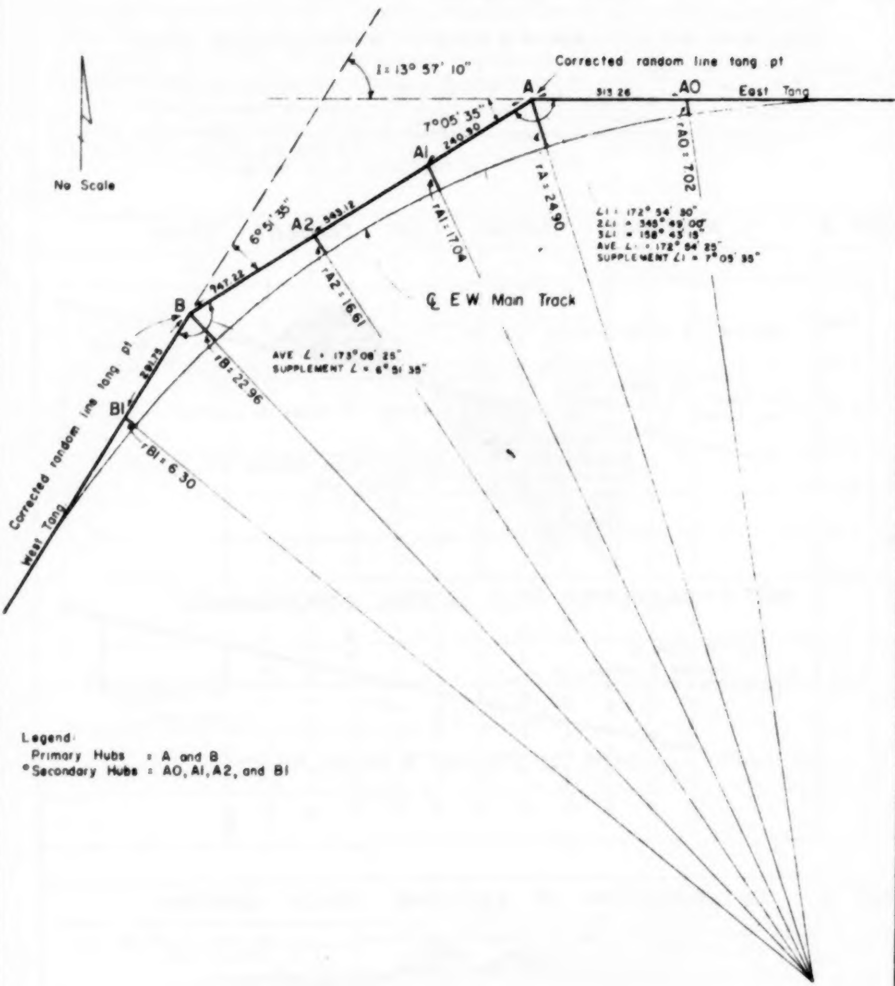


NEW YORK CENTRAL RAILROAD

COMPUTED BY: N.R.B. ENGINEERING DEPARTMENT

SUBJECT: FIGURE NO. 1 — Traverse, E.W. Curve

LOCATION: M.P. D-123.38 Battle Creek DIVISION: Michigan DATE: June 5, 1952



Legend:
Primary Hubs = A and B
*Secondary Hubs = AO, A1, A2, and B1

* Secondary hubs may fall on the inside of the curve

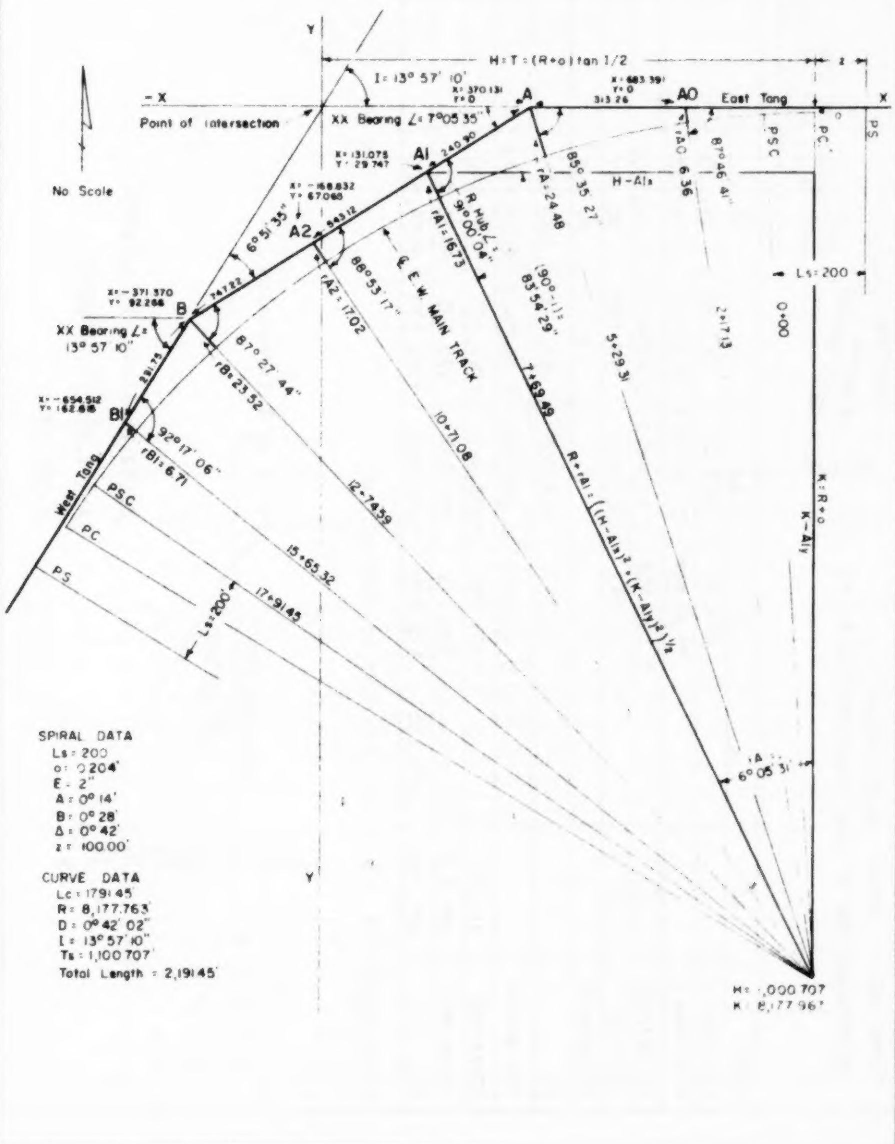
NEW YORK CENTRAL RAILROAD

ENGINEERING DEPARTMENT

COMPUTED BY: N.R.B.

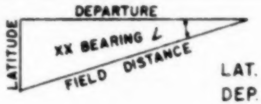
SUBJECT: FIGURE NO. 2 CURVE DATA – E.W. Curve

LOCATION: M.P. D-123.38 Battle Creek DIVISION: Michigan DATE: June 5, 1952



FORM NO. I CURVE M.P. 123.38

DETERMINATION OF HUB COORDINATES Px, Py



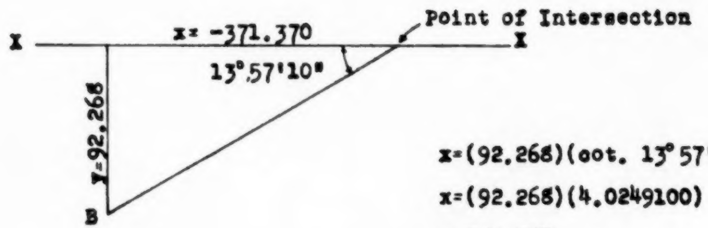
LAT. = (FIELD DIST.)(SIN XX BEARING ∠)

DEP. = (FIELD DIST.)(COS XX BEARING ∠)

Py = LAT. + ADJ. Px = DEP. + ADJ.

POINT	A0	A	A1	A2	B	B1		
FIELD DIST.			240.90	543.12	747.22	291.75		
XX BEARING ∠			7°05'35"	7° 05'35"	7°05'35"	13°57'10"		
SIN BEARING			0.1234812	0.1234812	0.1234812	0.2411221		
LATITUDE			29.747	67.065	92.268	70.347		
ADJUSTMENT			0	0	0	92.268		
Py			29.747	67.065	92.268	162.615		
COS. BEARING			0.9923469	0.9923469	0.9923469	0.9704948		
DEPARTURE	313.26		-239.056	-538.963	-741.501	-283.142		
ADJUSTMENT	370.131		370.131	370.131	370.131	-371.370		
Px	683.391	370.131	131.075	-168.832	-371.370	-654.512		

ESTABLISHMENT OF X & Y AXIS AT POINT OF INTERSECTION



x=(92.268)(cot. 13°57'10")

x=(92.268)(4.0249100)

x=371.370

FORM NO. 2 CURVE M.P. 123.38
Part A TRIAL CURVE DATA

TRIAL		NO. 1	NO. 2	NO. 3	NO. 4	NO. 5
CURVE DATA°	I	13°57'10"	13°57'10"	13°57'10"		
	I/2	6°58'35"	6°58'35"	6°58'35"		
	R	8,124.000	8,218.086	8,177.763		
	D			0° 42.038'		
SPIRAL DATA°	E	2"	2"	2"		
	Ls	200	200	200		
	o	0.205	0.203	0.204		
	z	100	100	100		
	A			0° 14.013'		
	B			0° 28.025'		
	Δ			0° 42.038'		
T				1,000.707		
Ts				1,100.707		
L p.c.-p.c.				1,991.452		
L p.s.c.-p.s.c.				1,791.452		
L p.s.-p.s.				2,191.452		

Part B TANGENT DISTANCES

H & K FOR SIMPLE SPIRALED CURVES
K = R + o
H = T = K Tan I/2
Ts = T + z

R	8,124.000	8,218.086	8,177.763		
o	0.205	0.203	0.204		
K	8,124.205	8,218.289	8,177.967		
Tan I/2	0.1223663	0.1223663	0.1223663		
H	994.129	1,005.641	1,000.707		
z			100.000		
Ts			1,100.707		

Part C RADIUS CORRECTION

$$\text{Approx. R Corr.} = \frac{\pm \text{Throw}}{\text{Exsec } I/2}$$

± Throw	0.70	-0.30			
Exsec. I/2	0.00744	0.00744			
R Corr.	94.086	-40.323			
Old R	8,124.000	8,218.086			
New R	8,218.086	8,177.763			

° Curve and spiral symbols taken from N.Y.C.R.R. standard Spiral Tables

FORM NO 3 CURVE MP 1233B

Part A THROW COMPUTATIONS

$R \pm r = \sqrt{(H-Px)^2 + (K-Py)^2}$

r computed = $(R \pm r) - R$

Throw = r computed − r measured

TRIAL	No. 1	No. 2						No. 3					
POINT	A1	A1	A0	A	A2	B	B1	A1	A0	A	A2	B	B1
H	994.129	1,005.641	1,005.641	1,005.641	1,005.641	1,005.641	1,005.641	1,000.707	1,000.707	1,000.707	1,000.707	1,000.707	1,000.707
−Px	−131.075	−131.075	−683.391	−370.131	168.832	371.370	654.512	−131.075	−683.391	−370.131	168.832	371.370	654.512
H−Px	863.054	874.566	322.250	635.510	1,174.473	1,377.011	1,660.153	869.632	317.316	630.576	1,169.539	1,372.077	1,655.219
K	8,124.205	8,218.289	8,218.289	8,218.289	8,218.289	8,218.289	8,218.289	8,177.967	8,177.967	8,177.967	8,177.967	8,177.967	8,177.967
−Py	−29.747	−29.747	0.000	0.000	−67.065	−92.268	−162.615	−29.747	0.000	0.000	−67.065	−92.268	−162.615
K−Py	8,094.458	8,188.542	8,218.289	8,218.289	8,151.224	8,126.021	8,055.674	8,148.220	8,177.967	8,177.967	8,110.902	8,085.699	8,015.352
−(R±r)°	−8,140.338	−8,235.112	−8,224.604	−8,242.824	−8,235.401	−8,241.867	−8,224.961	−8,194.495	−8,184.120	−8,202.241	−8,194.788	−8,201.287	−8,184.474
+R°	+8,124.000	+8,218.086	+8,218.086	+8,218.086	+8,218.086	+8,218.086	+8,218.086	+8,177.763	+8,177.763	+8,177.763	+8,177.763	+8,177.763	+8,177.763
r computed	−16.338	−17.026	−6.518	−24.738	−17.315	−23.781	−6.875	−16.732	−6.357	−24.478	−17.025	−23.524	−6.711
r measured●	+17.04	+17.04	+7.02	+24.90	+16.61	+22.96	+6.30	+17.04	+7.02	+24.90	+16.61	+22.96	+6.30
THROW	+0.70	+0.01	+0.50	+0.16	−0.70	−0.82	−0.57	+0.31	+0.66	+0.42	−0.42	−0.56	−0.41

Part B RADIUS HUB ANGLE COMPUTATIONS

$$\sin i \text{ or } \cos(90° - i) = \frac{H - Px}{R \pm r}$$

$$R \text{ Hub } \angle = (90° - i) + XX \text{ Bearing } \angle$$

H−Px								869.632	317.316	630.576	1,169.539	1,372.077	1,655.219
R±r								8,194.495	8,184.120	8,202.241	8,194.788	8,201.287	8,184.474
Sin i or Cos (90°−i)								0.10612393	0.03877216	0.07687850	0.14271742	0.16730021	0.20223890
i								6°05'31"	2°13'19"	4°24'33"	8°12'18"	9°37'51"	11°40'04"
90°−i								83°54'29"	87°46'41"	85°35'27"	81°47'42"	80°22'09"	78°19'56"
XX Bearing								7°05'35"	0°00'00"	0°00'00"	7°05'35"	7°05'35"	13°57'10"
R HUB ∠								91°00'04"	87°46'41"	85°35'27"	88°53'17"	87°27'44"	92°17'06"

Part C STATION COMPUTATIONS

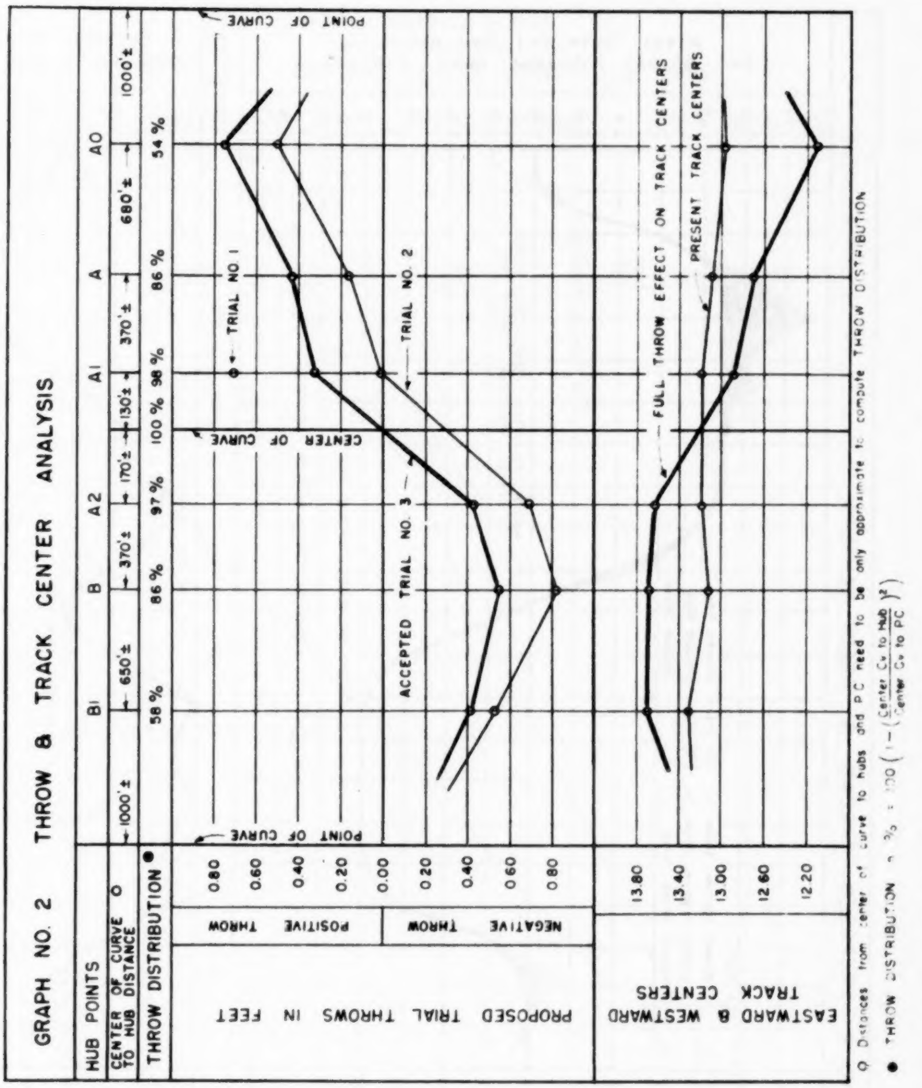
$$Li = \frac{I}{D}$$

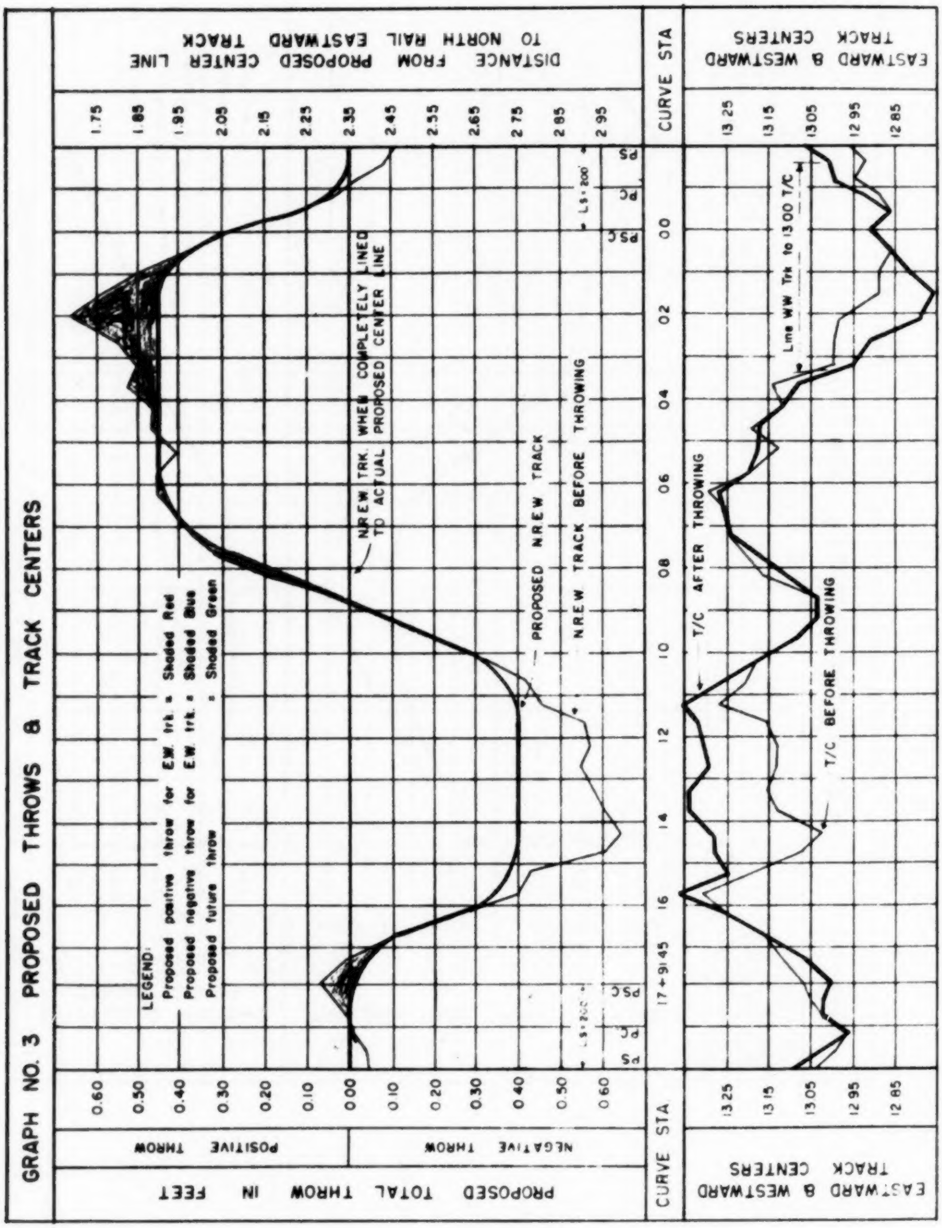
Sta = Li + Adj.

I								6.091 944	2.221 945	4.409 167	8.205 000	9.630 834	11.667 778
D								0.700 633	0.700 633	0.700 633	0.700 633	0.700 633	0.700 633
Li								869.49	317.13	629.31	1,171.08	1,374.59	1,665.32
Adjustment								100.00	100.00	100.00	100.00	100.00	100.00
STATION								769.49	217.13	529.31	1,071.08	1,274.59	1,565.32

° Assumed sign to accommodate throw sign

● Radial offsets measured from outside of curve assumed positive, from inside of curve assumed negative


GRAPH NO. 2 THROW & TRACK CENTER ANALYSIS
HUB POINTS
B1
B
A2
A1
A
AO
CENTER OF CURVE TO HUB DISTANCE ○
1000'±
650'±
370'±
170'±
130'±
370'±
680'±
1000'±
THROW DISTRIBUTION ●
58 %
86 %
97 %
100 %
98 %
86 %
54 %
PROPOSED TRIAL THROWS IN FEET
POSITIVE THROW
NEGATIVE THROW
0.80
0.60
0.40
0.20
0.00
0.20
0.40
0.60
0.80
POINT OF CURVE
CENTER OF CURVE
POINT OF CURVE
TRIAL NO. 1
TRIAL NO. 2
ACCEPTED TRIAL NO. 3
EASTWARD & WESTWARD TRACK CENTERS
13.80
13.40
13.00
12.60
12.20
FULL THROW EFFECT ON TRACK CENTERS
PRESENT TRACK CENTERS
○ Distances from center of curve to hubs and P.C. need to be only approximate to compute THROW DISTRIBUTION
● THROW DISTRIBUTION in % = 100 (1 − (Center Cv to Hub / Center Cv to PC)²)



GRAPH NO. 3 PROPOSED THROWS & TRACK CENTERS
LEGEND:
Proposed positive throw for E.W. trk. = Shaded Red
Proposed negative throw for E.W. trk. = Shaded Blue
Proposed future throw = Shaded Green
PROPOSED TOTAL THROW IN FEET
POSITIVE THROW
NEGATIVE THROW
DISTANCE FROM PROPOSED CENTER LINE TO NORTH RAIL EASTWARD TRACK
CURVE STA
EASTWARD & WESTWARD TRACK CENTERS
NREW TRK. WHEN COMPLETELY LINED TO ACTUAL PROPOSED CENTER LINE
PROPOSED NREW TRACK
NREW TRACK BEFORE THROWING
T/C AFTER THROWING
T/C BEFORE THROWING
Line WW Trk to 13.00 T/C
Ls=200'
PS
PC
PSC
17+91.45

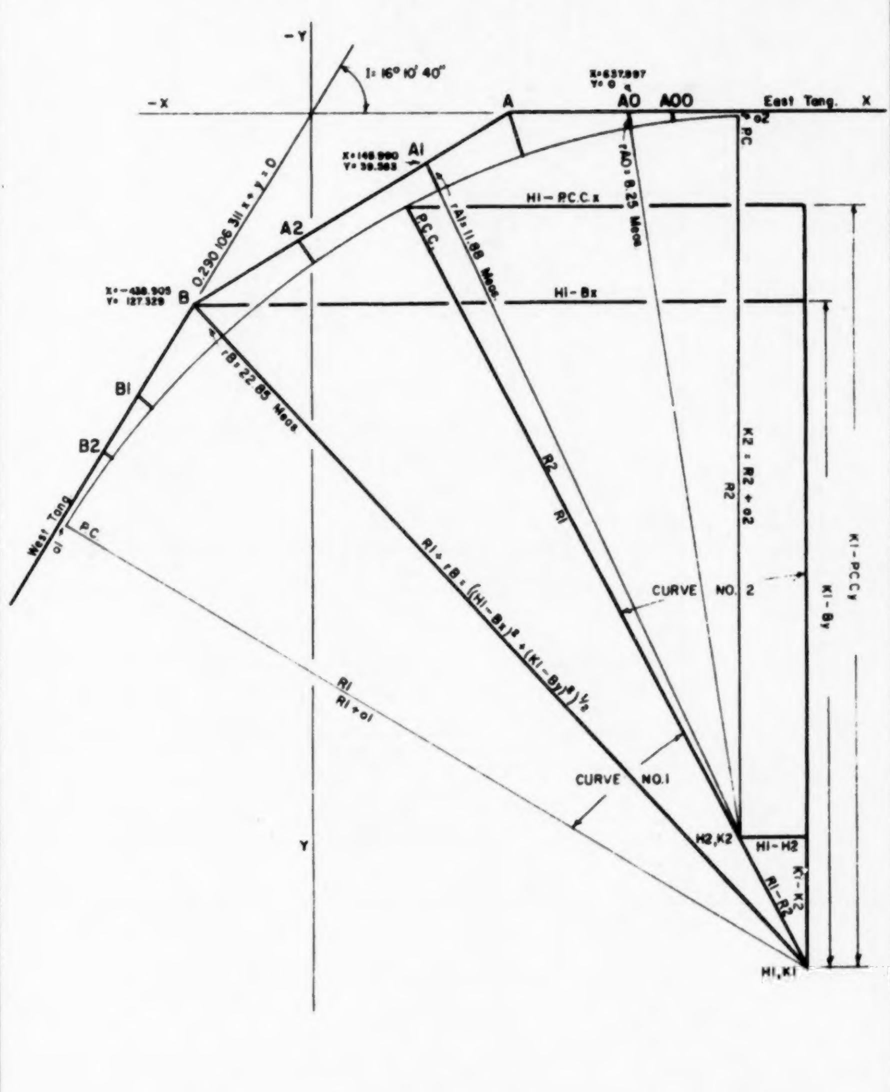
NEW YORK CENTRAL RAILROAD

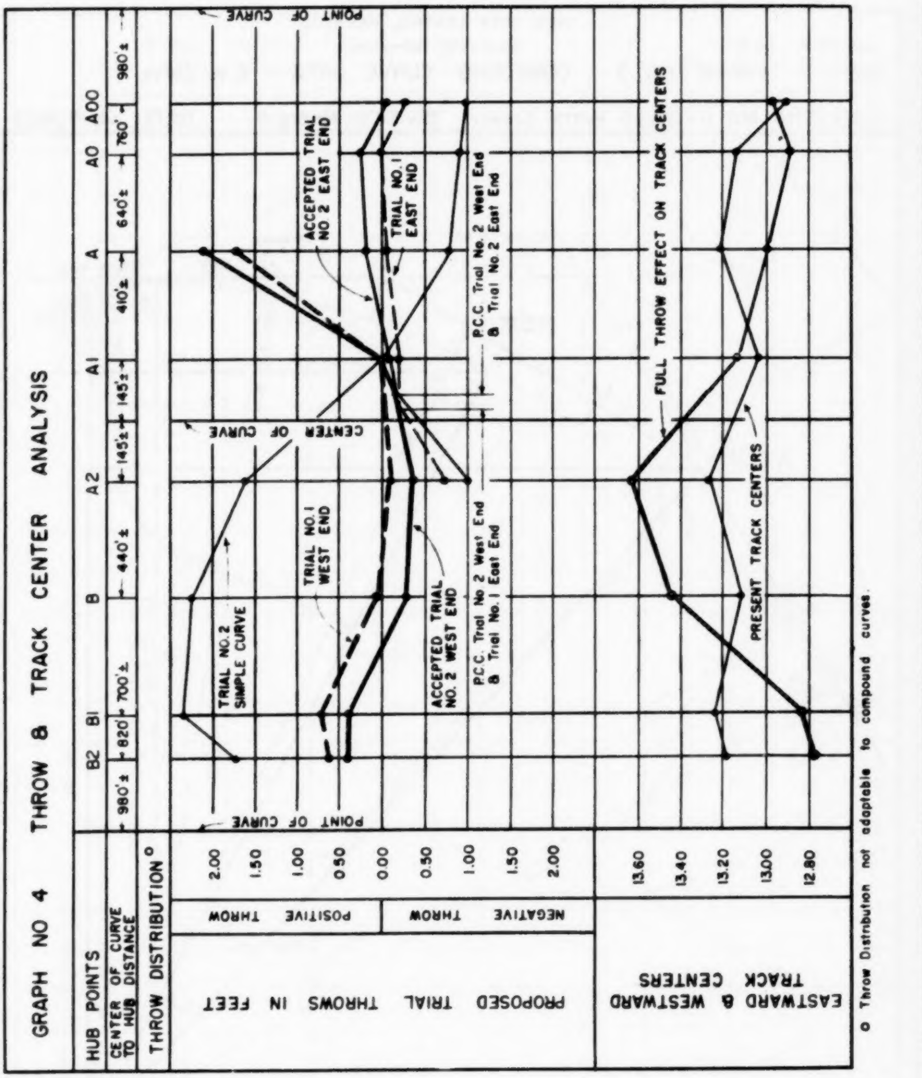
ENGINEERING DEPARTMENT

COMPUTED BY: J. C. M.

SUBJECT: FIGURE NO. 3 COMPOUND CURVE DATA – E.W. Curve

LOCATION: M.P. D-125.20 Battle Creek DIVISION: Michigan DATE: July 15, 1952




GRAPH NO 4 THROW & TRACK CENTER ANALYSIS
HUB POINTS
B2 B1 B A2 A1 A A0 A00
CENTER OF CURVE TO HUB DISTANCE
980'± 820' 700'± 440'± 145'± 145'± 410'± 640'± 760' 980'±
THROW DISTRIBUTION°
PROPOSED TRIAL THROWS IN FEET
POSITIVE THROW
NEGATIVE THROW
2.00
1.50
1.00
0.50
0.00
0.50
1.00
1.50
2.00
POINT OF CURVE
CENTER OF CURVE
POINT OF CURVE
TRIAL NO.2 SIMPLE CURVE
TRIAL NO.1 WEST END
ACCEPTED TRIAL NO. 2 WEST END
P.C.C. Trial No 2 West End & Trial No. 1 East End
P.C.C. Trial No. 2 West End & Trial No. 2 East End
ACCEPTED TRIAL NO 2 EAST END
TRIAL NO. 1 EAST END
EASTWARD & WESTWARD TRACK CENTERS
13.60
13.40
13.20
13.00
12.80
FULL THROW EFFECT ON TRACK CENTERS
PRESENT TRACK CENTERS
o Throw Distribution not adaptable to compound curves.